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ORNL

FOREIGN TRIP REPORT

TA 424783

DATE:	July 23, 2018
SUBJECT:	Report of Foreign Travel to Paris, France – Bradley T. Rearden, Reactor and Nuclear Systems Division
TO:	Angela Chambers, Nuclear Criticality Safety Program Manager, National Nuclear Security Administration / NA-511/GTN, Pantex Plant, PO Box 30020, Amarillo, TX 79120-0020
FROM:	Bradley T. Rearden
MEETING: TITLE	Working Party on Nuclear Criticality Safety (WPNCS)
MEETING: LOCATION	OECD/NEA Headquarters, Boulogne-Billancourt (Paris), France
MEETING: DATES	July 1–6, 2018
ATTENDEES: ON BEHALF OF NCSP	Bradley T. Rearden, William J. Marshall
MEETING: BENEFIT TO NCSP	Brad Rearden is the ORNL Modeling and Simulation Integration Lead and manager of the SCALE code system, which is licensed to over 8,500 users in 58 nations and includes NCSP supported methods and data for Monte Carlo neutron transport as well as sensitivity and uncertainty analysis, which are the topics of these meetings. Collaboration with international experts in these areas can lead to extended use of the NCSP-supported tools, identification of areas for improvements in existing methods, identification of new areas of research for the improvement of process design, and extended collaborative research and development.
MEETING PURPOSE:	Provide US leadership in the Organization for Economic Cooperation and Development (OECD) Working Party on Nuclear Criticality Safety (WPNCS) and its associated expert groups and technical subgroups in areas identified by international consensus to be important to nuclear criticality safety.
SITES VISITED:	OECD/NEA Headquarters, Boulogne-Billancourt (Paris), France

ABSTRACT: The OECD/WPNCS addresses scientific issues that lead to advancing the state-of-the-art in criticality safety practices, validation approaches, and computational tool and data development and use. The WPNCS provides a premiere venue for international experts determine which areas require advanced studies or further research and development though a collaborative consensus approach. At the conclusion of this meeting, the WPNCS reorganized its technical structure to eliminate long-running expert groups in favor more targeted technical subgroups, each focused on a specific task that is achievable in a 2-3 year timeframe. Each subgroup includes an elected chairman to coordinate the activity as well as an appointed expert Technical Monitor from the WPNCS committee. There are currently seven subgroups: 1) Role of Integral Experiment Uncertainties and Covariance Data in Criticality Safety Validation, 2) Blind benchmark on MOX damp powders, 3) A benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies, 4) Analysis of Past Criticality Accident, 5) Experimental needs for criticality safety purpose, 6) Statistical tests for diagnosing fission source convergence and undersampling in Monte Carlo criticality calculations, and 7) Sensitivity/uncertainty analysis on used fuel inventory. The main WPNCS committee meeting provides a venue for each subgroup chairman to provide a status report and for each nation to provide a technical report of the status of criticality safety activities in their country. Representatives were present from U.S., U.K., Canada, Belgium, Hungary, Italy, Sweden, Spain, Switzerland, France, Germany, Japan, Czech Republic, Finland, South Korea, Slovakia, and Germany.

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REPORT OF FOREIGN TRAVEL

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PURPOSE OF TRAVEL

The primary purpose of the travel to Paris is to participate in the Organization for Economic Cooperation and Development (OECD) Working Party on Nuclear Criticality Safety (WPNCS) and selected expert groups and technical subgroups of interest. Unfortunately, due to overlapping schedules, it was not possible to attend all desirable sessions.

The week commenced with the final meeting of the Expert Group on Used Nuclear Fuel. In this group, the spent fuel compositions for a BWR benchmark were computed by several teams with a variety of codes and nuclear data libraries. Even teams that used the same code and data version (e.g. 20 of the 37 results submitted used SCALE), the users interpretation of how to exercise the code created a wide spread of up to 25% variation on the isotopic inventories. By clearly specifying a number of additional constraints for the benchmark such a geometrical refinement and time steps, the variation of results with the same code and data were substantially reduced. The variation of results with different codes but with the same data (e.g. ENDF/B-VII.1) were also substantially reduced with these additional constraints. However, were different nuclear data libraries were used, even with the same code, a wide variation of predicted isotopics concentrations were still produced. As such, a joint proposal lead by CEA was brought forward to create a new subgroup (SG-7) "Sensitivity/uncertainty analysis on used fuel inventory" with chair Coralie Carmouze from CEA and technical monitor Brad Rearden from ORNL.

In the final meeting of the Expert Group on Advanced Monte Carlo Techniques, the final report draft on "User guidance to handle local tallies calculations in Monte Carlo eigenvalue simulation of loosely coupled systems" was reviewed by chair Eric Dumonteil of IRSN. This report documents a benchmark led by Brad Rearden and B.J. Marshall of ORNL with Chris Perfetti, formerly of ORNL, in addition to Eric Dumonteil of IRSN. The report documents a multi-year study in best practices for criticality safety analysts who wish to use local tallies from Monte Carlo simulations for quantities such a fluxes, reaction rates, and sensitivity coefficients. Several benchmark studies were conducted to identify what Monte Carlo sampling parameters are needed to ensure that correct results are generated. Where the quantity of interest is substantially undersampled (e.g. not enough Monte Carlo particles are used) the results can be substantially in error with no clear indication to the user. The report documents the results of this study a contributed by each team, as well as guidance for practitioners to avoid this issue, and the development of several new methods in SCALE that assist in diagnosing when this issue may be occurring (see C. M. Perfetti, B. T. Rearden, and W. J. Marshall, "Diagnosing Undersampling in Monte Carlo Eigenvalue and Flux Tally Estimates," *Nucl. Sci. Eng.,* **185**, 1 (2017)). At the conclusion of this meeting, additional activities were proposed by LANL's Forrest Brown to establish a new technical subgroup (SG-6) "Statistical tests for diagnosing fission source convergence and undersampling in Monte Carlo criticality calculations" with technical monitor John Bess of INL. Additional discussions were conducted for neutron clustering effects observed by some teams for small sample sizes, but actions in this area were deferred.

The first meeting of SG-1 on "Role of Integral Experiment Uncertainties and Covariance Data in Criticality Safety Validation" included an overview of the final report that is being transfer from the former Expert Group on Uncertainty Analysis for Criticality Safety Assessment (UACSA) to SG-1. This

SG is chair by Maik Stuke from GRS with technical monitor Brad Rearden from ORNL. The technical report documents a multiyear study in determining the correlation of criticality experiments that are currently treated as independent observations. However, the experiments selected for this exercise are comprised of the same fuel pins in the same grid plates at the same facility, so each experimental observation is related to the others. Numerous approaches have been applied by several expert teams, and there is a wide variation of the degree of correlation predicted by each team. If the highest correlations are assumed, the independence of the observations is largely eliminated, and the statistical confidence in the resulting upper subcritical limit (USL) is drastically reduced. In some cases, this change in independence can result in several *percent Δk* change in the USL for a safety case (see V. Sobes, B. T. Rearden, D. E. Mueller, W. J. Marshall, J. M. Scaglione, and M. E. Dunn, "Upper Subcritical Calculations Based on Correlated Data," ICNC 2015 – International Conference on Nuclear Criticality Safety, Charlotte, NC, September 13–17, 2015). The SG report will be completed in the coming months, and the next steps for experimental correlations will be determined by the team.

The meeting of SG-2 "Blind benchmark on MOX damp powders" included presentations on that validation of a challenging criticality safety scenario for which there are very few applicable benchmark experiments. The SG is a continuation of an activity from the former UACSA Expert Group. The SG is chaired by Coralie Carmouze from CEA and technical monitor Brad Rearden from ORNL. Results were presented where the SCALE/TSUNAMI methods were applied to clearly identify experiments that are and are not applicable to these systems, then the SCALE/TSURFER code was applied to integrate the validation coverage of each unique experiment to form a best estimate USL for the application cases. Results were also presented where MCNP/Whisper were applied to form a conservative USL. There are now submissions from six teams from five nations for this benchmark. The final report is expected to be published in the next year.

The WPNCS meeting included reports from each SG as well a country reports from each nation on the status of their criticality safety activities. Representatives were present from U.S., U.K., Canada, Belgium, Hungary, Italy, Sweden, Spain, Switzerland, France, Germany, Japan, Czech Republic, Finland, South Korea, Slovakia, and Germany. The U.S. country report is attached to the end of this document. All proposed SGs were approved by the WPNCS members. The organization of the International Conference on Nuclear Criticality Safety (ICNC) was discussed. This conference will be help September 16–20, 2019 at the Cité des Sciences et de l'Industrie in Paris. The 2019 WPNCS meeting will be held at the NEA headquarters the following week, September 23–27, 2019. Brad Rearden gave a presentation on the new DOE Office of Nuclear Energy Nuclear Data and Benchmarking Program that he leads as National Technical Director.

Persons Contacted at OECD/NEA

List of attendees will be available from NEA soon

Itinerary

06/30/18 – 07/01/18 Travel from Knoxville, USA to Paris, France
07/02/17 – 07/06/18 Attend WPNCS meetings at OECD/NEA (agendas attached, presentation materials available on WPNCS website)
07/07/18 Travel from Paris, France to Knoxville, USA

DISTRIBUTION

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US Country Report to the OECD-NEA Working Party on Nuclear Criticality Safety (NCS)
6 July 2018

National Context

The United States (US) has fissile material operations involving all portions of the nuclear fuel cycle. Research in the area of advanced reactor concepts continues to investigate use of fuel with > 5 wt.% enrichments, in the area of industrial and government activities the focus is on production and fabrication of reactor fuel with enrichments < 5 wt.%, and a growing interest in metallic fueled fast reactors, liquid fueled molten salt reactors, fluoride salt-cooled high temperature reactors, and high temperature gas reactors. Government and industry are also pursuing many concepts for accident tolerant fuels in cladding materials, with a lead test rod of iron-based accident tolerant cladding currently under irradiation in an operating plant. As the industry grows and develops, many criticality safety issues on the front end and back end of the fuel cycle will need to be addressed. The US Department of Energy (DOE) has stopped the planned MOX fuel fabrication plant, and thus the US has limited need for criticality safety relevant to the transport or storage of MOX fuel.

The current fiscal year 2018 budget request includes substantial funding to restart studies for the spent fuel repository site at Yucca Mountain, with indications from congress that this initiative will be supported. In 2016, the US Nuclear Regulatory Commission (NRC) received an application for a Consolidated Interim Storage Facility (CISF) in Andrews County, Texas from Waste Control Specialist. Staff performed acceptance reviews and issued a number of Requests for Supplemental Information (RSIs) prior to the applicant requesting the review to be placed on hold. In June 2018, the applicant requested the NRC to resume the review. The NRC received a second application for an interim storage facility from Holtec International in March 2017. The staff completed an acceptance review and the application is currently under acceptance review. Final repository options and overall storage, transport, and disposal systems are being studied by DOE to provide the technical information for future decisions regarding the back end of the fuel cycle.

The DOE, including its autonomous National Nuclear Security Administration (NNSA), and the NRC each have responsibility for providing regulatory oversight on criticality safety – DOE for operations within the DOE complex and NRC for industry operations. The American Nuclear Society (ANS) is the US professional organization that works to develop consensus standards for criticality safety and organize technical meetings on criticality safety. Each of these organizations develops, sponsors, or supports training classes and workshops to support education and knowledge exchange in the field of criticality safety. The number of universities offering classes and degree certificates focused on criticality safety has risen over the last few years.

Research and Development (R&D) Programmes

The DOE and NRC both support research activities in the area of nuclear criticality safety. The DOE Nuclear Criticality Safety Program (NCSP) has provided a central focus for research and technology development for over 15 years. The DOE NCSP (see

http://ncsp.llnl.gov/) has five elements: Integral Experiments, Analytical Methods, Nuclear Data, Information Preservation and Dissemination, and Training and Education. Integral experiments (and hands-on training classes) are conducted at the National Criticality Experiments Research Center (NCERC) in Nevada, run by Los Alamos National Laboratory, and at Sandia National Laboratories (SNL) in New Mexico.

All four critical experiment machines at NCERC (Planet, Godiva, Comet, and Flattop) are available, and the facility operates as a user facility to help meet national and international program needs.

The NCSP has conducted "hands-on" critical experiment training classes at NCERC during the past year. Specifically, each year the NCSP conducts two 2-week training class for NCS practitioners and two 1-week training course for regulators, managers, and operations professionals who need to understand the fundamentals of nuclear criticality safety. The 2-week classes include one week of classroom training at the Nevada Field Office in Las Vegas, NV, followed by one week of hands-on critical experiment training at either SNL or NCERC. The 1-week manager's courses focus on hands-on experience with less technical lectures and are also conducted at SNL or NCERC. Since establishing the NCSP hands-on training courses in 2011, over 300 students have taken the NCS hands-on training courses.

With regard to information preservation and dissemination, the NCSP revised a previous benchmark evaluation, LEU-COMP-THERM-079, through the course of its activities to prepare several additional benchmark evaluations for submission to the International Criticality Safety Benchmark Evaluation Project (ICSBEP) in the upcoming year. Efforts continue to encourage users of the ICSBEP Handbook to report errors and questions in order to suitably revise existing benchmark evaluation data currently found therein.

Integral experiment research over the last year has included: demonstration of a nuclear reactor for low power space applications (KRUSTY-Kilowatt Reactor Using Stirling Technology), completion of 6 of 10 novel plutonium (Pu) and tantalum (Ta) critical experiments using ZPPR (Zero Power Physics Reactor) fuel (part of the TEX series of experiments), a nuclear accident dosimetry exercise using Flattop, design work for HEU (highly enriched uranium) and ^{233}U TEX experiments, subcritical measurements such as SCRαP using the BERP ball, design of experiments to study the critical effects of plutonium aging, and design of titanium sleeve experiments in the BUCCX reactor at SNL. SNL efforts also include 7uPCX experimentation with varying large pitches. There is also ongoing interest in subcritical experiments at LANL using a Np sphere. Design work is being completed for two different temperature-dependent critical experiments; SNL and Oak Ridge National Laboratory (ORNL) are collaborating on a design of heating and cooling the water of the SNL water lattice and Lawrence Livermore National Laboratory (LLNL) is working with the United Kingdom's (UK's) National Nuclear Laboratory (NNL) and Los Alamos National Laboratory (LANL) to design a -40 °C variation on the uranium TEX experiments. Collaborative efforts with the Institute Jozef Stefan (IJS) in Slovenia includes benchmark evaluation of the LANL experiments using uranium foils moderated/reflected by Lucite.

With regard to Analytical Methods, Monte Carlo N-Particle (MCNP) and SCALE are key codes used for criticality safety within the DOE complex and are supported by the NCSP, with nuclear data libraries generated by NJOY and AMPX. A key area of development has been sensitivity/uncertainty methods using continuous energy data and investigating advanced validation methods. The multi-laboratory Nuclear Data Advisory Group (NDAG) prioritizes nuclear data measurements and evaluations supported by the NCSP and coordinates NCSP activities with the US National Nuclear Data Center to assure inclusion in the Evaluated Nuclear Data Files (ENDF). Funding to help support processing of ENDF data for the criticality safety codes is also provided by the NCSP, including expanded cross section covariance data are available for the key NCS analyses code packages. The ENDF/B-VIII.0 was released in late 2017 and has many new features including expanded thermal scattering data for reactor grade graphite and pyrolytic carbon needed for advanced reactors as well as water in ice form to temperatures below -40 °C as requested by International Atomic Energy Agency (IAEA) transportation guidelines. LANL participated in the development and recent release of the ENDF/B-VIII.0 nuclear data. ACE files for use with MCNP are now available for download on a public website. Fundamental R&D work that is continuing at LANL includes the investigation and development of: region-dependent sensitivity-uncertainty data for NCS validation, methods to diagnose and accelerate Monte Carlo source convergence, diagnostic tests for undersampling and clustering, the impact of correlated fission multiplicity models in criticality calculations, studies into the validation for chlorine, and more

The SCALE and MCNP teams both provided training classes to US and international participants. Classes in the theory and practice of Monte Carlo criticality calculations with MCNP6 are given regularly at LANL and other sites. A new 1-day training class on the use of sensitivity-uncertainty methods in NCS validation has also been conducted numerous times, by personnel from both LANL and ORNL. To help educate future nuclear engineers, the LANL methods and code developers are teaching 2 semester-long courses at the University of New Mexico. SCALE offers two weeks of training classes on criticality safety and uncertainty analysis methods at the OECD NEA as well as a week of training on spent fuel characterization at the National Research Nuclear University MEPhI (https://eng.mephi.ru) under NEA sponsorship. The MCNP and SCALE codes continue to be highly regarded Monte Carlo codes. LANL released a new version of MCNP – MCNP6.2 – through RSICC. The release includes the Whisper code to support sensitivity-uncertainty based methods for NCS validation. There are estimated to be 20,000 users of MCNP throughout the world. ORNL released SCALE 6.2.3 to provide enhanced capabilities and resolve various reported issues. More than 4,000 users have requested SCALE 6.2 over the past two years. SCALE is the most highly requested code from the NEA Data Bank, with distributions to over 2000 Data Bank members over the past decade, with mirrored distribution also available from the RIST data center in Japan.

In the Nuclear Data program element, prioritized nuclear data measurements and evaluations continue to be performed to support NCS operations in the US. During the past year, new differential measurements have been performed on natural vanadium (V) and zirconium (Zr) samples. Also, substantial progress has been made to expand the Rensselaer Polytechnic Institute (RPI) linear accelerator neutron capture measurement capabilities into the keV range that is important for many nuclei pertinent to criticality safety. Furthermore, the NCSP has partnered with NNSA Naval Reactors

to invest in an accelerator refurbishment effort at RPI to ensure the US has a differential data measurement capability for performing needed cross-section measurements. With regard to new cross-section evaluation work, the NCSP has completed new resonance region evaluations for ^{63,65}Cu, ^{56}Fe, ^{16}O, and ^{182,183,184,186}W. These new evaluations are undergoing testing and are expected to be available with the next release of the ENDF data library. A new initiative known as the Interagency Nuclear Data Working Group recently coordinated multi-faceted funding opportunity announcement for new nuclear data evaluations to support a number of priority programmatic needs for the DOE Office of Nuclear Physics, Isotope Program, Office of Nuclear Energy, NNSA/Defense Nuclear Nonproliferation Research and Development, Department of Homeland Security, and Domestic Nuclear Detection Office. It is hoped that substantial new initiatives will provided many updated nuclear data evaluations with high quality uncertainties will become available to the community. The DOE Office of Nuclear Energy has initiated a new Nuclear Data and Benchmarking Program that is focused on identifying gaps and providing enhancements in data measurement, evaluation, and covariance generation as well as benchmark experiments and application studies import to emerging nuclear energy applications, especially focused on advanced reactors and advanced fuels.

NRC continues its support for research focused on use of Burnup Credit in designing criticality control systems for Boiling Water Reactor (BWR) spent fuel storage casks and transportation packages. The first phase of research which was focused on BWR peak reactivity was completed by issuing a NUREG report entitled “Technical Basis for Peak Reactivity Burnup Credit for BWR Spent Nuclear Fuel in Storage for Transportation Systems”. The second phase of the research, which is examining beyond peak reactivity, is currently underway and is planned to be completed by the end of 2018. BWR research is being driven primarily by loss of geometry concerns of storing high burnup fuels and the planned extension of fuel storage time limits beyond 20 years.

International Collaborations

The NNSA continues to interact with Atomic Weapons Establishment (AWE) and NNL in the UK and the Commissariat à l'Énergie Atomique (CEA) and L'Institut de Radioprotection et de Sûreté Nucléaire (IRSN) in France to identify and collaborate on nuclear criticality safety issues of mutual interest, such as integral experiments, computational methods, and improved nuclear data. During the past year, the collaborations have resulted in personnel from the US performing collaborative work at IRSN, CEA, and AWE. Likewise, personnel from AWE, NNL, and IRSN have visited the US to perform collaborative work tasks at NCSP sites. Within the DOE NCSP, ORNL and Institute for Reference Materials and Measurements (IRMM) collaborate to perform neutron cross-section measurements in the resonance region to address differential data needs identified as important to improvement of nuclear criticality safety analyses.

Under OECD/NEA WPEC, US National Laboratories are working with other international partners on the CIELO (Collaborative International Evaluated Library Organization) to improve nuclear evaluations, many of which support improved evaluations for nuclear criticality safety. Specifically, the CIELO collaboration has focused efforts on completing new evaluations for ^{235}U, ^{238}U, ^{239}Pu, ^{56}Fe, and ^{16}O.

In addition, the NCSP provides support for the US participation in the ICSBEP. The DOE Office of Nuclear Energy Nuclear Data and Benchmarking Program now provides support for the US

leadership of the ICSBEP following past funding provided via the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program.

Future Challenges

Organizations face a continuing challenge to maintain a fully compliant criticality safety program with qualified personnel experienced in both the principles of criticality safety and the fissile material operations, with the need for planning to support the needs of the advanced reactor community. In addition, a challenge is related to the availability of experiments to use for benchmarks in criticality reviews to support analysis of accident tolerant fuels. A further challenge exists related to succession planning for key staff expertise needed to support NCS. To meet this challenge, the NCSP is continuing to invest in succession planning for key NCS technology capabilities that include specialists in integral experiments, nuclear data, and analytical methods.

Holdup residues can contribute significantly to the inventory of nuclear material within process equipment and, at any time, can represent the largest portion of inventory uncertainty. As such, these residues can challenge assumptions and limits needed for nuclear criticality safety. The NNSA has initiated work to establish a safety-related *in situ* nondestructive assay (NDA) program to manage and direct R&D tasks needed to improve NDA capabilities for quantifying nuclear material holdup. A mission and vision document for the NDA technology program is in development and should be published in the coming year.

Input to/from NEA NSC Programmes of Work

The US continues to engage in each of the Expert Groups and Subgroups of the Working Party on Nuclear Criticality Safety as well as in other NEA working parties. US participants are actively engaged or are leading activities within the Nuclear Science Committee WPNCS. The US leadership is provided for the WPNCS Expert Group on Used Nuclear Fuel, with the recent release of SFCOMPO-2.0. US leadership continues for ICSBEP and SFCOMPO. US leadership is also provided with the Technical Monitor for Uncertainty Analysis for Criticality Safety Assessment overseeing two subgroups. Involvement in other NSC activities include: Working Party on International Nuclear Data Evaluation Co-operation (WPEC), Working Party on Reactor Systems (WPRS), Expert Group on Improvement of Integral Experiments Data for Minor Actinide Management (EGIEMAM-II), Expert Group on Accident Tolerant Fuels for Light Water Reactors (EGATFL), The Working Party on Scientific Issues of the Fuel Cycle (WPFC), Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV), and WPEC Subgroups: 44 on Investigation of Covariance Data in General Purpose Nuclear Data Libraries, 45 on Validation of Nuclear Data Libraries (VaNDaL) Project, and 46 on Efficient and Effective Use of Integral Experiments for Nuclear Data Validation. Additionally, the US engages with the activities of Committee on the Safety of Nuclear Installations (CSNI) not listed here. These engagements are sponsored by numerous agencies, but the DOE/NNSA or NRC are the primary sponsor of the participants and their contributions.